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Anchorage of Stirrups in a Thin Cast-in-Place Topping

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Composite construction involving precast concrete and cast-in-place concrete is used extensively in building construction today. Fig. 1 shows a typical case in which a precast inverted tee ledger beam, supporting precast double tee beams, is made composite with a thin topping slab cast on top of the precast members. Shear must be transferred across the interface between the top of the precast inverted tee beam and the cast-in-place concrete.

In a case such as this, shear transfer reinforcement will usually be needed across the interface. If this reinforcement is to be effective, it must be anchored in the concrete on both sides of

Synopsis

Tests are reported of hook and loop stirrup anchorages in thin toppings cast against precast members. Variables included were stirrup size, topping thickness, topping concrete strength, rough or smooth interface, and tensile strain normal to the anchorage. It is shown that #3, #4 and #5 bar stirrups can be anchored in 3.0, 3.5 and 4 in. (75, 90 and 105 mm) thick, normal weight concrete toppings, respectively, if the topping concrete has a strength of at least 3000 psi (20.7 MPa).

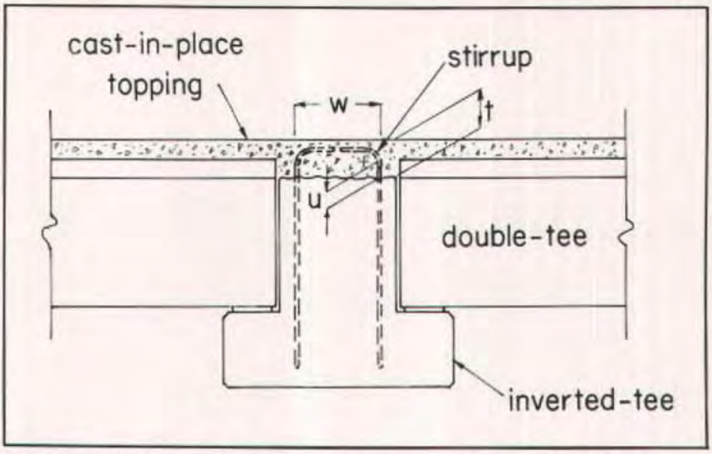

Fig. 1. Typical case of an inverted tee made composite with a cast-in-place topping.

the interface, so as to be able to develop its yield strength at the interface. However, the reinforcement development provisions of Chapter 12 of ACI 318-83[1] appear to indicate that such stirrup reinforcement could not be anchored in the thin cast-in-place topping.

This study was designed to investigate the feasibility of anchoring stirrup reinforcement in a thin cast-in-place topping. It was carried out in two phases:

Phase 1—This phase was concerned with the case in which there are no tension stresses in the topping slab, across the plane containing the anchorage. This was intended to correspond to the case of a simply supported composite beam, or to the positive moment region of a continuous composite beam.

Phase 2—This phase was concerned with the case in which tension exists in the topping slab, across the plane containing the anchorage. This was intended to correspond to the case of the negative moment region of a continuous composite beam, in which continuity reinforcement is provided in the cast-in-place topping.

The variables included in the study were as follows:

— Stirrup size: #3, #4, #5.
— Topping thickness: 2, 3 or 4 in. (51, 76 or 102 mm) in Phase 1, and 3 or 4 in. (76 or 102 mm) in Phase 2.
— Topping concrete strength: 2000, 3000 or 4500 psi (13.8, 20.7 or 31.0 MPa) in Phase 1, and 3000 or 4000 psi (20.7 or 27.6 MPa) in Phase 2.
— Type of interface: rough or smooth.
— Type of anchorage: 90 degree hook or closed loop.
— Tensile strain normal to the plane containing the anchorage: 0, 0.001 or 0.002, i.e., corresponding to zero stress or to a stress of 30 or 60 ksi (207 or 414 MPa) in the continuity reinforcement embedded in the cast-in-place topping.

The stirrups were all nominally Grade 60, but the actual yield strengths were between 60 and 73 ksi (414 and 503 MPa).

All the concrete was made from glacial outwash gravel, sand and Type III portland cement.

The strength of the precast concrete was approximately 6000 psi (41 MPa) in Phase 1 and 5000 psi (35 MPa) in Phase 2. The actual strengths of the reinforcement and of the topping concrete are given in Table 1.

Table 1. Test specimen properties (Phase 1).

Specimen No.	Stirrup size (#)	Stirrup yield strength f_y (ksi)	Lead-in length u (in.)	Cast-in-place topping thickness t (in.)	Cast-in-place topping strength f'_c (psi)
H-3-S-2	3	71.4	*	2	3100
H-4-S-2	4	67.5	*	2	3100
H-3-S-3	3	71.4	0.75	3	3200
H-4-S-3	4	67.5	0.25	3	3200
H-3-S-4	3	71.4	1.75	4	3000
H-4-S-4	4	67.5	1.25	4	3000
H-3-R-2	3	71.4	*	2	3000
H-4-R-2	4	67.5	*	2	3000
H-3-R-3	3	71.4	0.75	3	3000
H-4-R-3	4	67.5	0.25	3	3000
H-3-R-3A	3	72.9	0.75	3	2100
H-4-R-3A	4	68.8	0.25	3	2100
H-3-R-3B	3	72.0	0.75	3	4400
H-4-R-3B	4	65.1	0.25	3	4400
H-4-R-2.75	4	70.0	0.00	2.75	2900
H-5-R-3.25	5	66.2	0.00	3.25	2900
C-3-S-3	3	71.5	0.75	3	3300
C-4-S-3	4	67.5	0.25	3	3300
L-3-S-3	3	71.4	0.75	3	2900
L-4-S-3	4	66.6	0.25	3	3000

*Hook not completely embedded. Topping not thick enough to contain entire hook with ¾ in. cover over tail.

Note: 1 ksi = 6.895 MPa; 1 psi = 6.895 kPa; 1 in. = 25.4 mm.

TEST PROGRAM

Test Specimens

Phase 1 — Fig. 2 shows the type of specimen used in this phase of the study. The upper 12 in. (305 mm) wide by 10 in. (254 mm) thick precast concrete block represents a piece of the web of a typical inverted tee section. The two legs of the stirrup pass through plastic tubes in this block and are anchored in the topping cast on top of the precast concrete block.

In eighteen specimens, the anchorage of each stirrup leg consisted of a 90 degree hook, having an inside bend diameter of six bar diameters and a tail of six bar diameters. In two specimens the anchorage consisted of a closed loop joining the two stirrup legs, the bend diameter being six bar diameters. The concrete cover to the tail of the hook and to the outside of the loop anchorage was ¾ in. (19 mm). The lower ends of the stirrups were anchored in another precast concrete block, with a bar of equal diameter welded across their ends.

The precast part of the specimen was cast on its side. The face of the precast concrete block against which the topping was later cast, was cast either against a smooth form or against a form with a ribbed surface. The latter produced a waffle type pattern on the face of

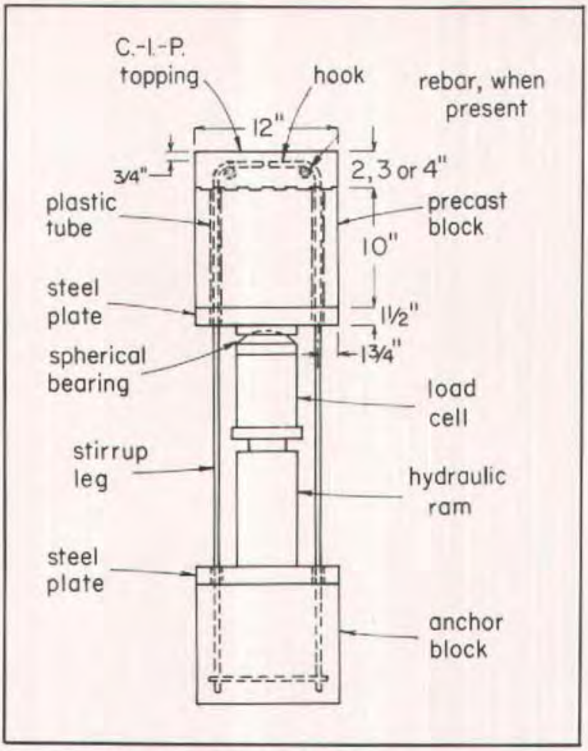

Fig. 2. Typical Phase 1 specimen.

the precast block. This pattern has a vertical height of ¼ in. (6 mm) and was intended to provide a standardized degree of roughness approximating that specified by Section 11.7.9 of ACI 318-83.[1]

Two days after casting, the forms were stripped and metal spacer plates were screwed to the heavy steel plates on opposite sides of the specimen. This was to maintain its alignment when it was lifted into a vertical position, so that the topping could be cast. Caulking was placed around each stirrup leg in the top of the plastic tubes, so as to prevent mortar running down the tubes when the topping was cast on the fourth day. Testing of specimens took place from 3 to 6 days later.

Each specimen is identified by a group of four characters, as seen in Table 1. The first character is H when a hook anchorage was used, L when a loop anchorage was used, and C when a horizontal bar was embedded in the topping inside and at right angles to the hooks. The second character is the size of the stirrup reinforcing bar. The third character is S for a smooth interface and R for a rough interface. The fourth character is the thickness of the topping concrete in inches.

Phase 2 — A typical specimen used in Phase 2 of the study is shown in Fig. 3. The composite beam specimen consisted of a 12 in. x 12 in. x 10 ft (305 mm x 305 mm x 3.05 m) long precast concrete beam, with either a 3 or 4 in. (76 or 102 mm) thick cast-in-place topping, in which were embedded two #10 reinforcing bars. The top surface of the precast beam was roughened to a full

Table 2. Test specimen properties (Phase 2).

Specimen No.	Stirrup size (#)	Stirrup yield strength f_y (ksi)	Lead-in length u (in.)	Cast-in-place topping thickness t (in.)	Cast-in-place topping strength f'_c (psi)
H-3-1-3	3	60.0	0.75	3	3020
H-3-2-3	3	60.0	0.75	3	3020
H-4-1-3	4	65.7	0.25	3	3140
H-4-2-3	4	65.7	0.25	3	3140
H-4-1-4	4	65.7	1.25	4	3150
H-4-2-4	4	65.7	1.25	4	3150
H-4-1-4A	4	65.7	1.25	4	2780
H-4-2-4-A	4	65.7	1.25	4	2780
H-5-1-4	5	63.6	0.75	4	4100
H-5-2-4	5	63.6	0.75	4	4100
L-3-1-3	3	60.0	0.75	3	3020
L-3-2-3	3	60.0	0.75	3	3020
L-4-1-3	4	65.7	0.25	3	3140
L-4-2-3	4	65.7	0.25	3	3140
L-4-1-4	4	65.7	1.25	4	3150
L-4-2-4	4	65.7	1.25	4	3150
L-4-1-4A	4	65.7	1.25	4	2780
L-4-2-4A	4	65.7	1.25	4	2780
L-5-1-4	5	63.6	0.75	4	4100
L-5-2-4	5	63.6	0.75	4	4100

Note: 1 ksi = 6.895 MPa; 1 psi = 6.895 kPa; 1 in. = 25.4 mm.

amplitude of ¼ in. (6 mm), as specified in Section 11.7.9 of ACI 318-83.[1]

The four, two-legged stirrups to be tested were located centrally in the beam at 6 in. (152 mm) centers, and projected 28 in. (711 mm) below it. They passed through plastic tubes in the precast beam and were anchored in the cast-in-place topping, either by 90 degree hooks (as used in Phase 1), or by a closed loop joining the two legs, with bend radii of three bar diameters. In both cases the cover to the horizontal parts of the anchorages was ¾ in. (19 mm). The stirrup bars passed around the longitudinal flexural reinforcing bars. These bars were located below the points of tangency of the horizontal parts of the stirrup anchorage and the 90 degree bends.

Small transverse grooves were formed in the cast-in-place topping above each test stirrup, to ensure that flexural cracks would occur at the location of each anchorage, and so create the most adverse conditions for the anchorage.

Four days after casting, the precast beam was placed on 3 ft (0.9 m) high steel chairs. The formwork for the cast-in-place topping was clamped to the beam and the test stirrups were put in position, passing through the plastic tubes in the beam. The space between the stirrups and the plastic tubes was caulked and the topping was cast. Testing took place 3 days later.

Each anchorage tested is identified by a group of four characters, as seen in Table 2. The first, second, and fourth characters have the same significance as in Phase 1. However, in Phase 2 the third character is 1 or 2 depending upon whether the tensile strain in the flexural reinforcement was 0.001 or 0.002.

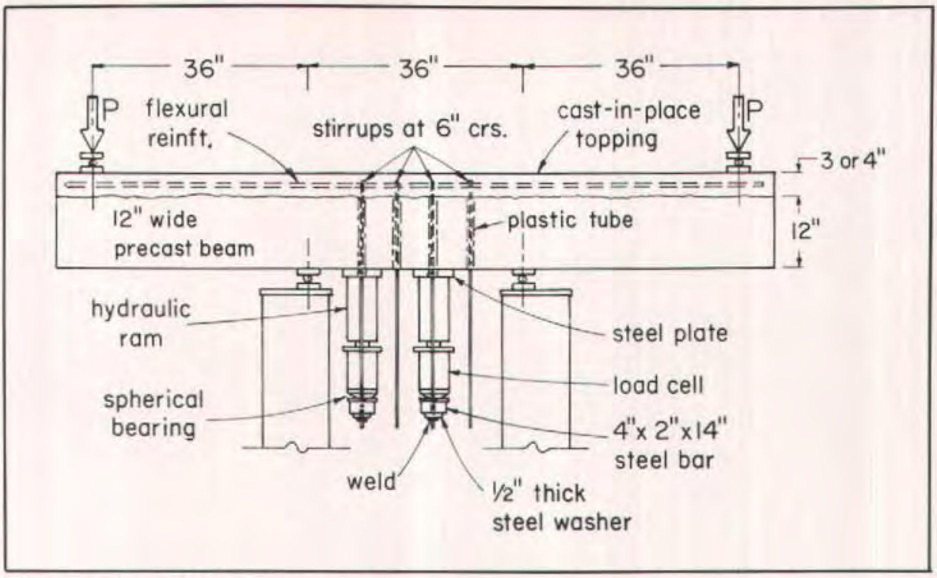

Fig. 3. Typical Phase 2 specimen.

Arrangements for Test

Phase 1 — The stirrup was loaded by a hydraulic ram placed centrally on the steel plate covering the anchor block. This pushed against the steel plate below the precast block through a load cell and a spherical bearing, as shown in Fig. 1. The plate between the ram and the load cell was recessed on both faces, so as to align the ram and load cell. A pin projecting from the top of the load cell located the spherical bearing concentrically. The entire loading arrangement was aligned very carefully, so as to ensure that both stirrup legs would be loaded equally.

Phase 2 — The specimen was supported at points 18 in. (457 mm) each side of its middle, and was subject to equal loads 36 in. (914 mm) outside each support, creating tension in the flexural reinforcement embedded in the cast-in-place topping. These loads were applied by a hydraulic testing machine acting through a 10 ft (3 m) long steel distribution beam. This beam rested on the roller bearings seen in Fig. 3.

As in Phase 1, the stirrup anchorages to be tested were loaded by a hydraulic ram acting through a load cell and a spherical bearing. This is shown in Fig. 3. In this case the load was transferred to the stirrup legs by a 4 x 2 x 14 in. (102 x 51 x 356 mm) steel bar below the spherical bearing. The weight of the loading equipment was initially carried by external threaded rods passing through this bar and through a cross bar resting on the top face of the beam.

A ½ in. (13 mm) thick steel washer was then passed over the end of each stirrup leg and was clamped to the steel bar while welds were made between each washer and stirrup leg. The nuts on the ends of the external threaded rods were then loosened, so that the stirrup legs could be loaded, and also so that no confinement was provided to the top face of the cast-in-place topping above the stirrup anchorages.

Instrumentation

In both phases of the test program, the slip of the anchorage of each stirrup leg at the interface between the cast-in-

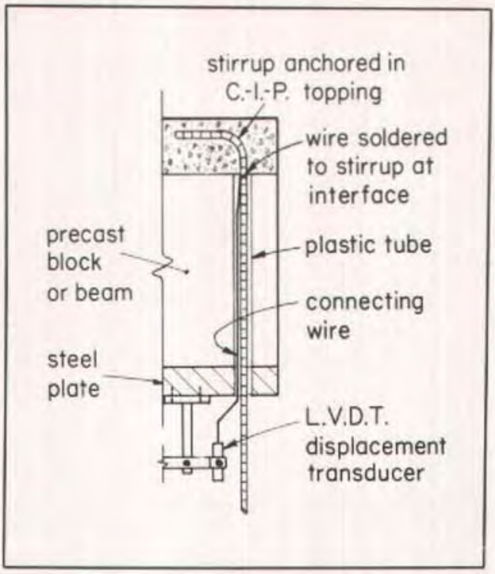

Fig. 4. Arrangements for measuring the slip of a stirrup leg, at the interface between the precast member and cast-in-place concrete.

place and precast concretes, was measured by a linear variable differential transformer (LVDT). Each LVDT was securely gripped in an adjustable brass mount, which was attached to the steel plate below the precast concrete block or beam.

As shown in Fig. 4, a connecting wire was soldered to the stirrup legs at the point where the slip was to be measured, and was connected to the core of the LVDT through a brass extension piece. The outputs from the LVDTs and from the load cell measuring the applied load were monitored continuously by a strip chart recorder.

In Phase 2 the strain in the flexural reinforcement embedded in the cast-in-place topping was measured by electrical resistance strain gages located at midspan. A transverse groove was formed in the cast-in-place topping above the strain gages, to ensure that a flexural crack would occur at that location.

Test Procedures

Phase 1 — With the ram, load cell and spherical bearing snugly in place, the screws were removed which connected the temporary alignment plates to the steel plate below the precast block. The oil pressure supplied to the ram was then increased slowly. The applied load and the slip of the anchorages was monitored continuously. The top surface of the cast-in-place topping was watched carefully, and any cracks which developed were marked and recorded. The load was progressively increased until failure occurred.

Phase 2 — The loads applied at each end of the composite beam specimen were increased incrementally until a strain of 0.001 was recorded in the embedded flexural reinforcement at midspan. Screw jacks were then inserted below each load point to prevent the deformation of the beam increasing while the stirrup anchorage tests were carried out.

The anchorages of two stirrups were then tested in turn, using the same procedure as in Phase 1. One of these stirrups had 90 degree hook anchorages and one had a loop anchorage.

The screw jacks were removed and the beam loads were increased until a strain of 0.002 was recorded in the embedded flexural reinforcement. The screw jacks were then re-inserted below each load point, to stabilize deformation of the beam while the anchorages of the remaining two stirrups were tested. As before, one of these stirrups had 90 degree hook anchorages and one had a loop anchorage.

TEST RESULTS

Specimen Behavior

Failure occurred either by rupture of the stirrup or by anchorage failure involving fracture of the topping concrete. In the first case, fine cracks occurred in the top face shortly before failure in about two-thirds of the tests, but they did not widen at failure. In the second case, cracks were observed in the top face just before failure in about half of the tests.

The anchorage failures were violent. They occurred as a result of splitting of the cast-in-place topping in the plane of the loop or hooks, or by breaking out of the concrete cover above the tails of the 90 degree hooks, or by a combination of these two modes of failure. Anchorage failures occurred both before and after yield of the stirrups, and did not appear to be precipitated by yield of the stirrups. In some of the specimens with a smooth interface, when splitting of the topping in the plane of the anchorage occurred, the splitting crack propagated along the interface. In most splitting failures, cracks propagated outward from the splitting crack and broke through the top face 2 or 3 in. (51 or 76 mm) from the splitting crack.

The failures by rupture of the stirrups occurred between the upper and lower blocks in the Phase 1 tests, but at or near the weld at the bottom of the stirrup legs in the Phase 2 tests. However, these failures occurred at reinforcement stresses from 18 to 56 percent above the yield stress.

In Phase 2, seven tests ended before failure, in three cases the ram ran to maximum extension, and in four cases the maximum capacity of the ram was reached. The yield strength of the stirrup reinforcement was, however, exceeded in all these cases.

The maximum load and maximum stirrup stress attained in each test are given in Tables 3 and 4 for Phases 1 and 2, respectively. Also listed in these tables are the failure modes of the specimens.

Discussion of Test Results

Typical load-slip curves for hook anchorages with zero tension across the plane containing the hook are shown in Fig. 5. These curves are for #4 bar stirrups having a yield stress of 67.5 ksi (465 MPa), anchored in 3000 psi (20.7 MPa) concrete of either 2, 3 or 4 in. (51, 76 or 102 mm) thickness, and with either a rough or a smooth interface. All of these anchorages failed by fracture of the topping concrete.

It can be seen that for loads up to about 4 kips (17.8 kN), the load-slip curves were almost identical for the anchorages in the 3 and 4 in. (76 and 102 mm) thickness toppings. At higher loads the anchorage in the 4 in. (102 mm) topping was stiffer than those in the 3 in. (76 mm) topping, of which that with the rough interface was the stiffer. The stiffnesses of both anchorages in the 2 in. (51 mm) topping were essentially the same until close to failure, but were only about one-third of the initial stiffness of the anchorages in the 3 and 4 in. (76 and 102 mm) toppings. The different behaviors were probably due to the fact that the 2 in. (51 mm) topping could not

Table 3. Test results (Phase 1).

Specimen No.	Maximum load (kips)	Maximum stress, f_u (ksi)	$\frac{f_u}{f_y}$	$\frac{f_u}{60}$	Failure type
H-3-S-2	8.00	72.7	1.02	1.21	F3
H-4-S-2	8.90	44.5	0.66	0.74	F3
H-3-S-3	12.25	111.4	1.56	1.86	R
H-4-S-3	12.25	61.3	0.91	1.02	F1
H-3-S-4	12.25	111.4	1.56	1.86	R
H-4-S-4	17.26	86.3	1.28	1.44	F3
H-3-R-2	7.70	70.0	0.98	1.17	F1
H-4-R-2	9.76	48.8	0.72	0.81	F1
H-3-R-3	12.00	109.1	1.53	1.82	R
H-4-R-3	14.00	70.0	1.04	1.17	F3
H-3-R-3A	9.90	90.0	1.23	1.50	F2
H-4-R-3A	13.10	65.5	0.95	1.09	F2
H-3-R-3B	12.90	117.3	1.63	1.96	R
H-4-R-3B	16.50	82.5	1.27	1.38	F3
H-4-R-2.75	12.85	64.3	0.92	1.07	F3
H-5-R-3.25	19.00	61.3	0.93	1.02	F3
C-3-S-3	11.75	106.8	1.49	1.78	R
C-4-S-3	12.75	63.8	0.95	1.06	F3
L-3-S-3	11.50	105.6	1.48	1.76	R
L-4-S-3	20.25	101.3	1.52	1.69	F1

R = Rupture of stirrup.
F1 = Splitting of concrete in plane of stirrup.
F2 = Breaking out of concrete cover to tail of hook.
F3 = Combination of F1 and F2.

Note: 1 kip = 4.45 kN; 1 ksi = 6.895 MPa.

completely accommodate the hook on the #4 stirrup, while the 3 and 4 in. (76 and 102 mm) toppings could accommodate both the hook and short straight "lead-in" lengths of 0.25 and 1.25 in. (6.4 and 31.8 mm), respectively.

The incomplete embedment of the hook in the 2 in. (51 mm) topping also resulted in maximum loads of only 66 and 72 percent of yield for the smooth and rough interface cases, respectively. Although the yield strength of the stirrup was developed in the case of the 3 in. (76 mm) topping with a rough interface, the beneficial effect of the greater embedment possible in the 4 in. (102 mm) topping is clearly evident. The maximum load in this latter case was 128 percent of yield, reached at a slip about three times that which occurred at yield. In the case of the 3 in. (76 mm) topping and rough interface, the slip at yield was about one-third greater than that in the 4 in. (102 mm) topping case, and the slip at the maximum load of 104 percent of yield was only about 25 percent greater than that at yield.

In general, for the case of zero tensile strain across the plane containing the hook, the slip at stirrup yield was between 0.025 and 0.050 in. (0.64 and 1.27 mm). When the failure load exceeded

Table 4. Test results (Phase 2).

Specimen No.	Maximum load (kips)	Maximum stress, f_u (ksi)	$\frac{f_u}{f_y}$	$\frac{f_u}{60}$	Condition at maximum load
H-3-1-3	8.75	79.6	1.33	1.33	E
H-3-2-3	9.25	84.1	1.40	1.40	E
H-4-1-3	16.50	82.5	1.26	1.38	F3
H-4-2-3	15.50	77.5	1.18	1.29	F3
H-4-1-4	15.50	77.5	1.18	1.29	R
H-4-2-4	17.00	85.0	1.29	1.42	F1
H-4-1-4A	18.00	90.0	1.37	1.50	R
H-4-2-4A*	—	—	—	—	—
H-5-1-4	20.00	64.5	1.01	1.08	H
H-5-2-4	20.00	64.5	1.01	1.08	H
L-3-1-3	9.50	86.4	1.44	1.44	E
L-3-2-3	8.00	72.7	1.21	1.21	R
L-4-1-3	18.00	90.0	1.37	1.50	R
L-4-2-3	16.00	80.0	1.22	1.33	R
L-4-1-4	17.25	86.3	1.31	1.44	R
L-4-2-4	16.50	82.5	1.26	1.38	R
L-4-1-4A	18.00	90.0	1.37	1.50	R
L-4-2-4A	17.00	85.0	1.29	1.42	R
L-5-1-4	20.00	64.5	1.01	1.08	H
L-5-2-4	20.00	64.5	1.01	1.08	H

*Test terminated before failure (instrumentation problem).
R = Rupture of stirrup at or near weld.
F1 = Splitting of concrete in plane of stirrup.
F2 = Breaking out of concrete cover to tail of hook.
F3 = Combination of F1 and F2.
E = Ram run to maximum extension without failure.
H = Ram capacity reached without failure.

Note: 1 kip = 4.45 kN; 1 ksi = 6.895 MPa.

yield by 20 percent or more, the slip at stirrup yield was about 0.03 in. (0.76 mm).

Fig. 6 shows the variation with the cast-in-place topping thickness, of the maximum load per stirrup leg for hook anchorages. It can be seen that for zero tensile strain across the hook, the load at anchorage failure by fracture of the concrete increased with topping thickness at the same rate for both #3 and #4 stirrups, for both rough and smooth interfaces. This rate of increase in maximum load was about 4 kips (17.8 kN) for each 1 in. (25 mm) increase in topping thickness. The #3 stirrups just reached yield at anchorage failure in a 2 in. (51 mm) thick topping.

Also plotted in Fig. 6 are the maximum loads per #4 stirrup leg, for tensile strains across the hook of 0.001 and 0.002, for topping thicknesses of 3 and 4 in. (76 and 102 mm). In this case the increase in strength with increase in topping thickness is not as great as in the case of zero strain. However, the strengths attained with tension across the anchorage are not less than those attained with zero strain across the anchorage.

The hook on the #3 bar stirrup was 0.25 in. (6.4 mm) short of complete em-

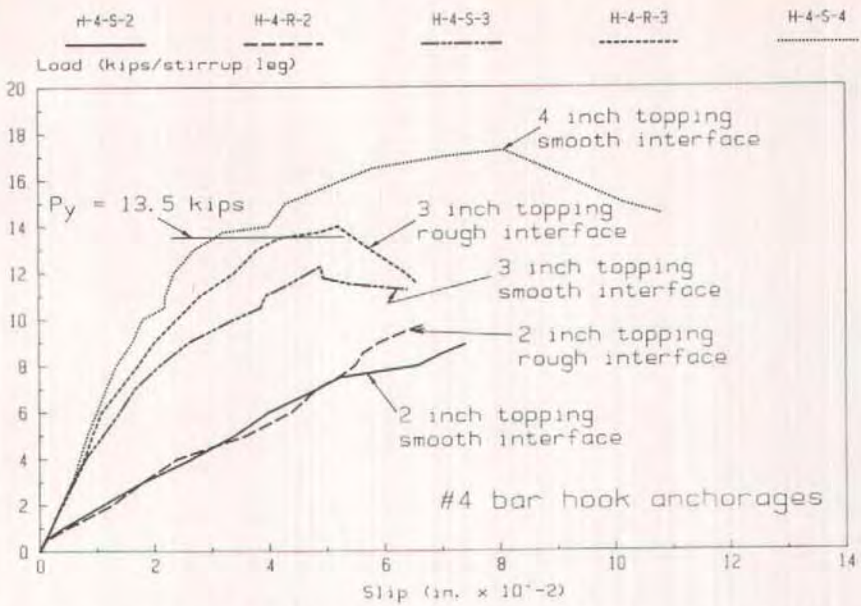

Fig. 5. Typical load-slip curves, hook anchorages with zero tension across the plane of the hook [$f_c' = 3000$ psi (21 MPa)].

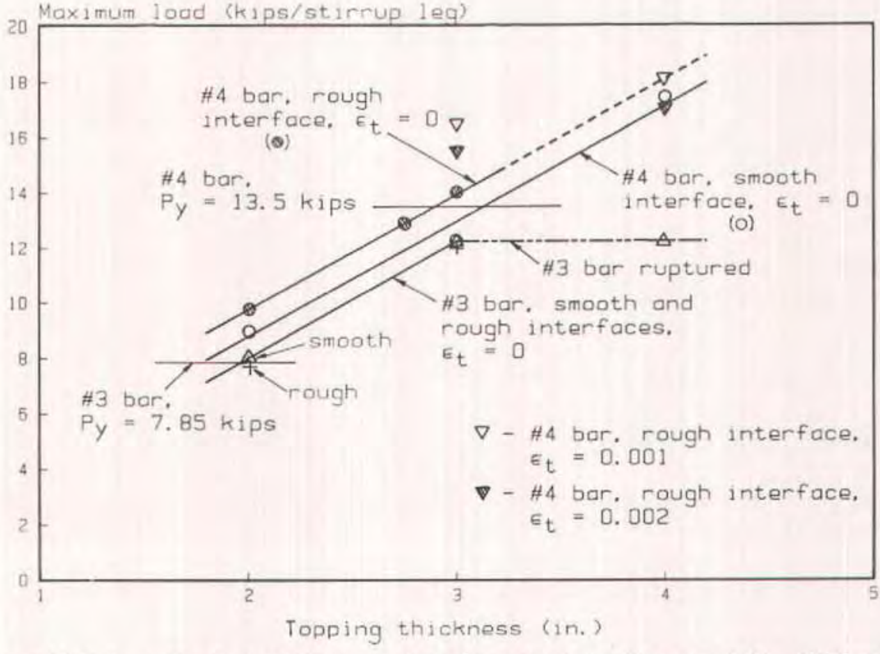

Fig. 6. Variation with topping thickness of maximum load per stirrup leg [$f_c' = 3000$ psi (21 MPa)].

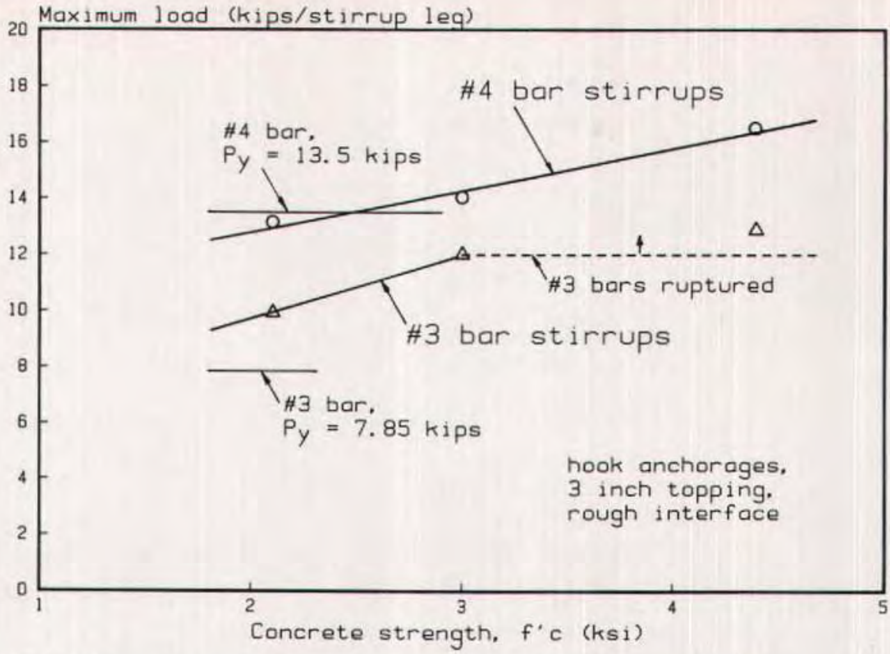

Fig. 7. Variation with topping concrete strength of maximum load per stirrup leg.

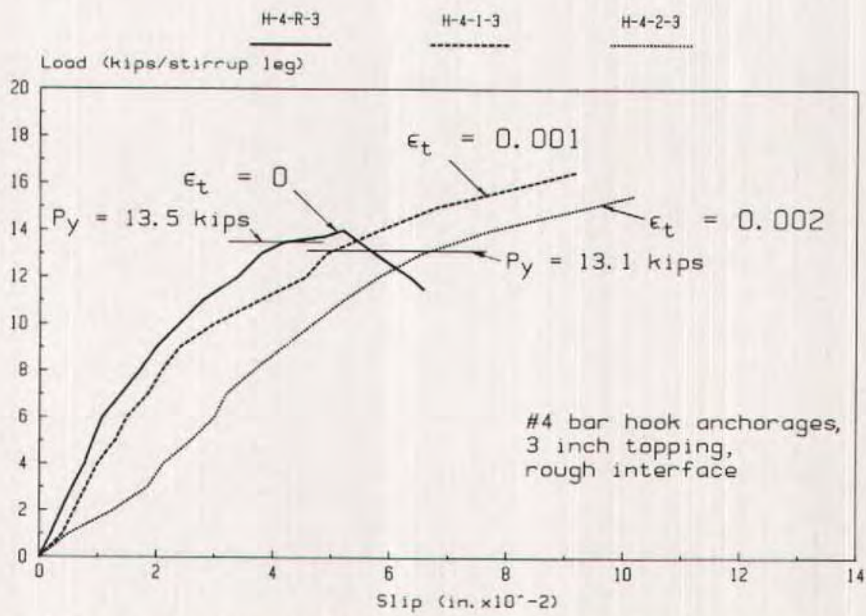

Fig. 8. Influence of tension across the plane of the hook, on the load-slip curves of hook anchorages.

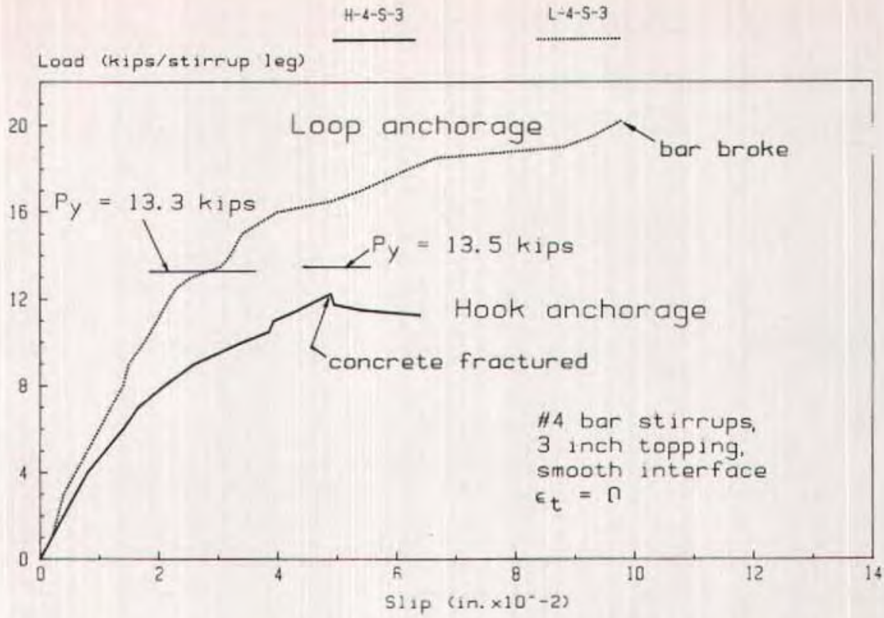

Fig. 9. Comparison of load-slip curves for hook and loop anchorages (smooth interface and zero tension across the plane of the anchorage).

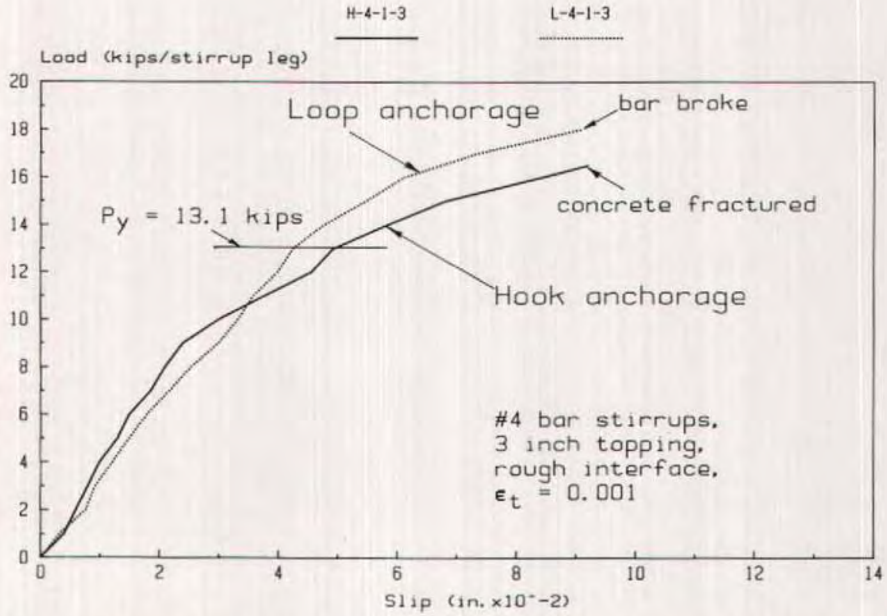

Fig. 10. Comparison of load-slip curves for hook and loop anchorages (rough interface and 0.001 tension strain across the plane of the anchorage).

bedment in the 2 in. (51 mm) thick topping, and developed a maximum stress of about 70 ksi (483 MPa) with both rough and smooth interfaces. Specimens H-4-R-2.75 and H-5-R-3.25 were, therefore, made with topping thicknesses that just provided complete embedment of the hooks on the #4 and #5 stirrups used. In these cases, the respective maximum stresses developed were 64.3 and 61.3 ksi (443 and 423 MPa). It can be said, therefore, that when complete embedment is provided for the hooks on #3, #4 and #5 stirrups in 3000 psi (20.7 MPa) normal weight concrete, a stress in excess of 60 ksi (414 MPa) can be developed. However, more favorable load-slip behavior results if the topping thickness, t, is sufficient to provide a straight lead-in length, u, to the hook of about ¾ in. (20 mm).

The variation of maximum load per stirrup leg with the compressive strength of the topping concrete is shown in Fig. 7 for the case of a 3 in. (76 mm) thick topping. The load at anchorage failure is not proportional to the concrete compressive strength, but increases at a much slower rate. This is consistent with the anchorage failure being due to tensile failure of the concrete, since the tensile strength of concrete does not increase in direct proportion to the compressive strength.

In Fig. 8 is shown the influence of tensile strain across the plane of the anchorage, on the load-slip curve for #4 bar hook anchorages embedded in a 3 in. (76 mm) topping of 3000 psi (20.7 MPa) concrete, and having a rough interface between the cast-in-place and precast concretes. All three of these anchorages failed by fracture of the concrete. It is seen that the maximum load was not reduced by the existence of a tensile strain across the anchorage. In fact, the anchorages from Phase 2, with tension acting across them, developed higher maximum loads than did the anchorage from Phase 1, with no tension acting across it. This was probably due to the difference in type of specimen. In the Phase 2 specimen, adjacent stirrup anchorages produce splitting forces which react against one another. This will delay splitting of the concrete and hence increase the strength of the anchorage. There is only one stirrup anchorage in the Phase 1 specimen, so this beneficial effect cannot occur. Fortunately, the Phase 2 specimen is more representative of the situation in an actual composite beam. However, it is also clear that tensile strain across an anchorage reduces its stiffness, so that the slip at yield of the stirrup is increased significantly.

In Figs. 9 and 10 comparisons are made between the load-slip curves of hook and loop anchorages on #4 bar stirrups anchored in a 3 in. (76 mm) topping of 3000 psi (20.7 MPa) concrete. In both pairs of specimens the loop anchorage developed a higher strength than did the hook anchorage. This is probably because the prying action of the tail of the hook on the cover concrete does not occur in the case of a loop anchorage. In the specimens shown in Fig. 9 there was a smooth interface between the precast and cast-in-place concretes and in this case the hook anchorage did not develop the yield strength of the stirrup, but the loop anchorage did. Also the hook anchorage was significantly less stiff than the loop anchorage. In these specimens a tensile strain of 0.001 existed across the anchorages and the slip at yield is about one-third greater than in the case of the loop anchorage shown in Fig. 9.

Specimens C-3-S-5 and C-4-S-3 were identical to Specimens H-3-S-3 and H-4-S-3, except that a piece of reinforcing bar of the same size as the stirrup was placed horizontally inside the hook. This bar was at right angles to the plane of the hook and was in contact with the inside of the hook at the point of tangency of the tail of the hook. It can be seen in Table 3 that there was no significant difference in the strengths of the comparable specimens. Specimen C-3-S-3 was 0.50 kips (2.2 kN) less strong than Specimen H-3-S-3, and C-4-S-3 was 0.50 kips (2.2 kN) stronger than Specimen H-4-S-3. Therefore, the presence of a reinforcing bar inside and at right angles to a hook anchorage cannot be expected to increase the strength of the anchorage. This is probably because considerable slip and deformation of the anchorage would have to occur before a significant bearing force could be developed between the anchorage and the transverse bar.

CONCLUSIONS

The following conclusions are drawn from the study described above. They relate to the anchorage in normal weight concrete of stirrups made from reinforcing bars of size #5 or less.

1. In composite beams, stirrups can be anchored in a relatively thin cast-in-place topping by standard 90 degree hooks or by a closed loop of width 9 in. (230 mm), the anchorages being either normal to the axis of the beam or parallel to the axis of the beam but not closer than 5 in. (125 mm) to the edge of the interface.

2. A standard 90 degree hook completely embedded in a topping of 3000 psi compressive strength concrete and having ¾ in. (20 mm) cover over its tail, can develop a maximum stress of at least 60 ksi (414 MPa). However, with this amount of embedment of the hook the failure characteristics are undesirable; there being little reserve strength beyond 60 ksi (414 MPa) for the #4 and #5 bar stirrups, and the slip at maximum load being not much greater than the slip at which the yield strength of the bar is developed.

3. The failure characteristics can be greatly improved by the provision of a ¾ in. (20 mm) lead-in length, u, of bar between the bottom of the cast-in-place topping and the point of tangency of the hook. This will result in the maximum load being about 25 percent above the yield strength, and it will occur at a slip much greater that the slip at yield.

4. The use of a closed loop with an inside bend diameter of six bar diameters and an overall width, w, of at least 9 in. (230 mm), in place of 90 degree hooks on each stirrup leg, results in a somewhat higher maximum load when failure occurs as a result of fracture of the concrete. (Assuming the same topping thickness and the same cover to the horizontal part of the anchorages in both cases.)

5. The anchorage strength of 90 degree hooks and loop anchorages used in the negative moment region of a composite beam, will not be reduced by the presence of tensile strains acting across the planes containing the anchorages, as a result of negative moments acting on the beam. However, the slip at maximum load will increase as the magnitude of the tensile strain increases.

6. Increasing the topping concrete compressive strength has only a small effect on the anchorage strength of both 90 degree hooks and loop anchorages. [Increasing the concrete strength from 2100 to 4400 psi (14.5 to 30.3 MPa) only resulted in an increase in anchorage strength of 26 percent, when failure occurred as a result of fracture of the concrete.]

* * *

DESIGN RECOMMENDATIONS

1. Either standard 90 degree hooks or closed loop anchorages of overall width, w, at least 9 in. (230 mm), both placed at right angles to the axis of the member, or placed parallel to the axis of the member but not closer than 5 in. (125 mm) to the edge of the interface, may be used to anchor stirrups of size #5 or smaller in cast-in-place toppings made composite with precast beams.

2. The minimum thicknesses, t, of normal weight concrete toppings in which #3, #4 and #5 bar stirrups are anchored should be 3.0, 3.5 and 4 in. (75, 90 and 105 mm), respectively, if the cover above the stirrup anchorage is ¾ in. (20 mm). If the cover is greater, the minimum topping thickness should be increased by the amount by which the cover provided exceeds ¾ in. (20 mm). The compressive strength of the topping concrete should be not less than 3000 psi (20.7 MPa).

ACKNOWLEDGMENT

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REFERENCE

1. ACI Committee 318, "Building Code Requirements for Reinforced Concrete (ACI 318-83)," American Concrete Institute, Detroit, Michigan, 1983.

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NOTE: Discussion of this article is invited. Please submit your comments to PCI Headquarters by August 1, 1988.